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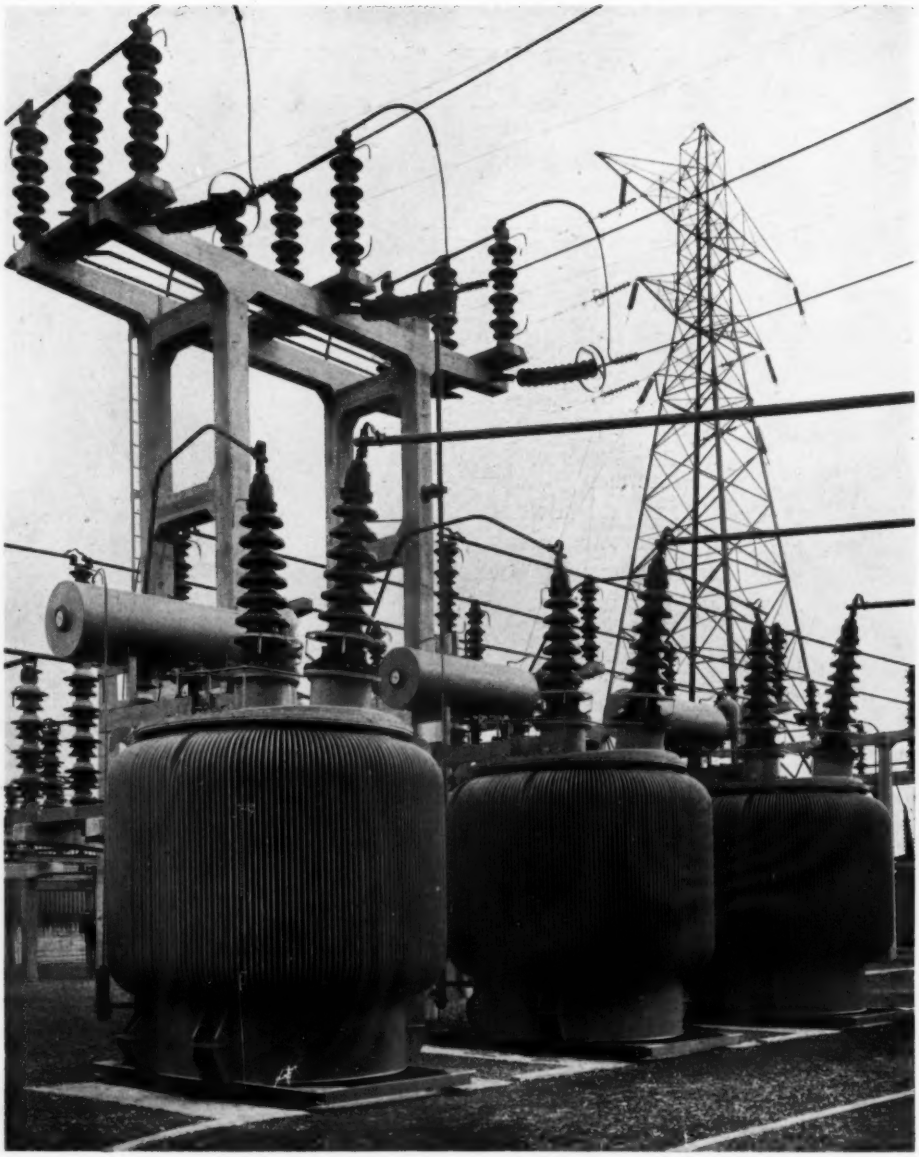


"English Electric" 132 kV. Reactors at the Percival Lane substation of the Central Electricity Board.

The English Electric Journal

Vol. X. No. 13 AUGUST, 1946. One Shilling

Errors and Corrections in Meter Testing.

By G. F. TAGG, B.Sc., Ph.D., M.I.E.E., F.Inst.P., Fel.A.I.E.E.

Introduction.

When electricity supply meters are being tested, whether at a manufacturers' works or in the test room of an electricity supply undertaking, care must be exercised to eliminate as many sources of error as possible. This is invariably done, but there are a few points which are not always correctly appreciated and may introduce quite serious errors in the results of such tests.

Meters are usually tested against a rotating sub-standard meter, which in turn is checked against a standard wattmeter and stop watch. The results for the standard or sub-standard instruments are often given in the form of corrections, usually given as a percentage, which when positive must be added to the instrument reading and when negative subtracted. This is exactly opposite to an error, which, when positive means that the meter or instrument is giving too high a reading and a percentage must be subtracted to give the correct result. Thus, errors and corrections must not be confused, as if an error is treated as a correction or vice versa, the resulting error will be twice that which would have resulted if the error or correction had been ignored.

A number of meters are usually tested simultaneously using phantom load circuits, and all the voltage circuits are connected in parallel. Here it is essential to keep the resistance of the leads connecting the voltage circuits to a very low value, as the induction type of meter takes a lagging current and the voltage drop on the connecting leads will produce a phase change in the voltages applied to successive meters and where a considerable number of meters are concerned, an interconnecting resistance of a small fraction of an ohm can cause sufficient phase change in the voltage applied to the last meter to introduce an error which can amount to 1 per cent. or more. A similar effect is produced when a bank of meters is connected to the voltage source and the sub-standard meter by long leads.

In metering equipments, meters are often employed in conjunction with current and voltage transformers, and it is generally impracticable to test the combination of meter and transformers together. The usual procedure is to test the transformers separately, and from their ratio and phase angle errors to deduce a correction which must be applied to the meter readings. This must be done carefully and methodically to ensure that no mistake is made, a thing which it is very easy to do.

The above are only three of the possible sources of error and are discussed in greater detail below ; there are, of course, other points which must be watched if the maximum possible accuracy is to be obtained, such as the correct spacing apart of meters, the presence of iron in large masses in close proximity to the meters, etc.

Errors and Corrections in Sub-Standard Instruments.

All N.P.L. certificates state the results of tests on instruments in the form of a correction, which when positive, must be added to the instrument reading, and this practice is often adopted for all instruments or meters of the standard and sub-standard classes. The results of tests on the ordinary house service meters, however, are usually given as errors, and a positive error indicates that the meter is reading high.

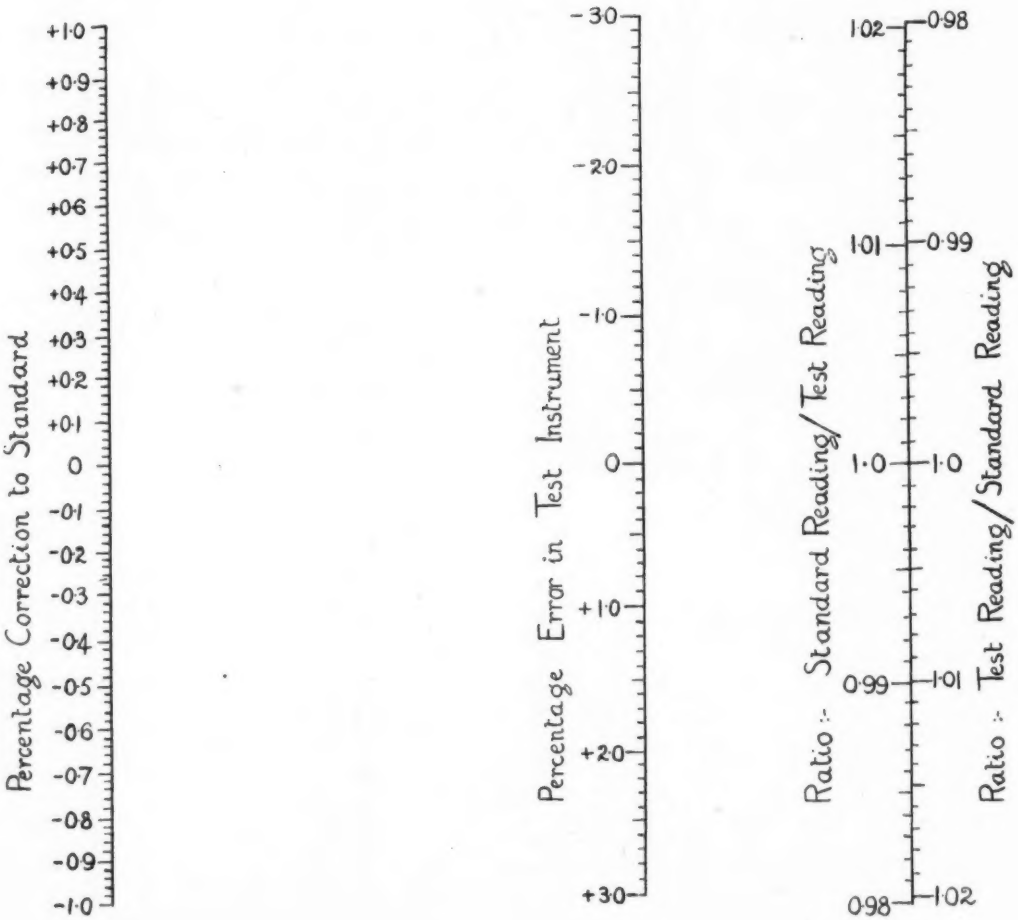


Fig. 1.—*Nomogram giving connection between correction in standard and error in test instruments.*

Let the reading of the standard or sub-standard instrument or meter ... $=\theta_1$

Let the correction of the standard or sub-standard instrument or meter ... $=x\%$

Let the reading of the test instrument or meter... ... ... $=\theta_2$

Let the *error* of the test instrument or meter ... ... $=y\%$

Then the true reading $= \theta_1\left(1+\frac{x}{100}\right)$

The error in the test instrument $= \frac{y}{100} = \frac{\theta_2 - \theta_1\left(1+\frac{x}{100}\right)}{\theta_1\left(1+\frac{x}{100}\right)}$

or $\frac{y}{100} = \frac{\frac{\theta_2}{\theta_1} - \left(1+\frac{x}{100}\right)}{\left(1+\frac{x}{100}\right)}$

It should be noted that the error can be expressed in terms of the ratio of the readings of the test and sub-standard instruments and as one of these is usually set to a whole number value it is usually possible by a simple and quick calculation to determine the value of one of the ratios.

$\frac{\text{Reading of standard instrument}}{\text{Reading of test instrument}} = \frac{\theta_1}{\theta_2}$ or,

$\frac{\text{Reading of test instrument}}{\text{Reading of standard instrument}} = \frac{\theta_2}{\theta_1}$

A nomogram is given in Fig. 1 from which it is possible to determine the percentage error in the test instrument, given one of these ratios and the percentage correction of the standard instrument. As an example, suppose the test instrument reads 99.7, the standard 100.0 and that the correction to the standard is +0.2 per cent. The ratio $\theta_2/\theta_1=0.997$ and an application of the nomogram gives the error as —0.5 per cent. In this case the result is fairly obvious from the figures alone. As another example, suppose the test instrument to read 39.7, the standard 40, and that the standard correction is —0.5 per cent. The nomogram gives the percentage error in the test instrument as —0.23 per cent.

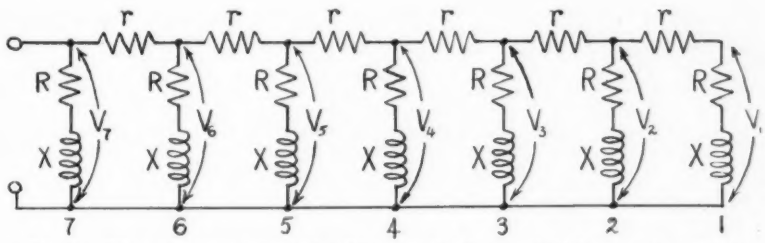


Fig. 2.—Schematic arrangement of voltage circuits of a number of meters in parallel.

Effect of Lead Resistance.

Consider a bank of meters with their voltage circuits in parallel, as shown in Fig. 2.

Let R = the alternating current resistance of the voltage coil.
X = the reactance of the voltage coil.
r = the resistance of the interconnecting leads, all assumed equal.
n = the number of meters.
V_1, V_2, V_3 = voltage across successive meter coils.

It is now necessary to determine the value of the voltage V_1 relative to the voltage Vn, which is the voltage applied to the bank of meters.

The current taken by meter No. 1 at the end of the line $= V_1/(R+jX) = V_1/Z$, say where Z is the impedance (R+jX) of the meter.

Hence the voltage across the second meter

$$=V_2=V_1+r\,\frac{V_1}{Z}=V_1\left(1+\frac{r}{Z}\right)=V_1\,(1+\alpha) \text{ say}$$

where $\alpha=\dfrac{r}{Z}$

Current taken by meter No. $2=V_2/Z$

The voltage across meter No. 3

$$=V_3=V_2+r.\frac{V_2}{Z}+r.\frac{V_1}{Z}$$
$$=V_2+\alpha V_2+\alpha V_1$$
$$=V_1\,(1+\alpha)+\alpha V_1\,(1+\alpha)+\alpha V_1$$
$$=V_1\,(1+3\alpha+\alpha^2)$$

Now $\alpha=r/Z$ is very small, so that powers of r/Z may be neglected.

Hence $V_3=1+3\alpha$

Similarly, it may be shown, ignoring all powers of α above the first,

$$V_4=V_1\,(1+6\alpha)$$
$$V_5=V_1\,(1+10\alpha)$$
$$V_6=V_1\,(1+15\alpha)$$

$$V_n=V_1\left(1+n\,\frac{(n-1)}{2}\,\alpha\right)$$

Again $\dfrac{n(n-1)\,\alpha}{2}$ will be small so that powers above the first may be neglected so that

$$V_1=\frac{Vn}{1+n(n-1)\,\frac{\alpha}{2}}=V_n\left(1-\frac{n\,(n-1)}{2}\,\alpha\right)=V_n\left(1-\frac{n(n-1)}{2}\,\frac{r}{R+jX}\right)$$

On re-arrangement this gives

$$V_1=V_n\left(\frac{2\,(R^2+X^2)-n(n-1)\;Rr+j\;X\;rn(n-1)}{2\,(R^2+X^2)}\right)$$

This means that the voltage V_1 leads the voltage Vn by an angle β such that

$$\tan\beta=\frac{n\,(n-1)\,Xr}{2\,(R^2+X^2)-n\,(n-1)\,Rr}$$

and has a magnitude such that

$$\frac{V_1}{V_n}=\left[1-\frac{n\,(n-1)\,Rr}{(R^2+X^2)}+\frac{n^2\,(n-1)^2\,r^2}{4\,(R^2+X^2)}\right]^{1/2}$$

For the Type UVB meter wound for 230 volts 50 cycles, R = 1,430 ohms and X = 8,540 ohms approximately, so for these meters

$$\tan\beta=\frac{6n\,(n-1)\,r}{105{,}000-n\,(n-1)\,r}$$

and $$\frac{V_1}{V_n}=\left[1-\frac{n\,(n-1)\,r}{52247}+\frac{n^2(n-1)^2\,r^2}{300\times10^6}\right]^{1/2}$$

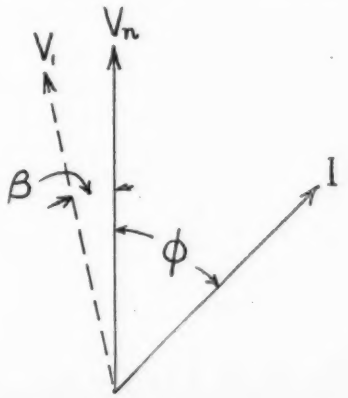


Fig. 3.—Vector diagram showing relation between supply voltage Vn and Voltage V_1 across last meter in a bank connected in parallel.

The effect of this on the registration of the last meter, i.e., meter No. 1, in Fig. 2, is illustrated in the vector diagram of Fig. 3. The applied voltage is Vn, the current is I lagging by an angle ϕ, the true registration should therefore correspond to a power $V_n I \cos \phi$. The voltage actually applied to meter No. 1 is V_1 leading V_n by an angle β, so that the registration will correspond to a power $V_1 I \cos (\phi+\beta)$. The error is therefore

$$\frac{V_1 I \cos(\phi+\beta) - V_n I \cos\phi}{V_n I \cos\phi} \times 100\%$$

$$= \frac{V_1}{V_n}\left(\cos\beta - \sin\beta \tan\phi\right) - 1 \times 100\%$$

The error is dependent on the power factor, and becomes greater as the power factor decreases, and some curves are given in Fig. 4 showing the errors introduced at 0.5 lagging power factor in the registration of the last type UVB meter in a number of meters, for various numbers of meters and values of interconnecting resistance. As an example, if there are 20 meters with an interconnecting resistance of 0.05 ohm, the error is approximately —0.2 per cent., while with 40 meters and the same resistance the error is approximately —0.85 per cent.

Another form of the same error may appear in any case where a bank of meters is connected to the sub-standard and the source of supply by long leads or by leads having an appreciable resistance. The error is, however, less in magnitude since the effect is not cumulative as it is in the previous case.

Suppose a bank of n meters is connected to a source V volts and the sub-standard instrument by leads having a total resistance of r_1 ohms. Also let V_m be the voltage applied to the meters. Then the current taken by the meters $= nVm/Z$ where $Z = R + jX$ as before. Then

$$V = V_m + r_1 \times \frac{nVm}{Z}$$

$$= V_m\left(1 + \frac{nr_1}{R+jX}\right)$$

$$\text{or } V_m = \frac{V\,(R + jX)}{R + nr_1 + jx}$$

This gives the voltage V_m leading in front of V by an angle β given by

$$\tan\beta = \frac{n\,r_1\,X}{R\,(R+n\,r_1)+X^2}$$

and the numerical value of V_m is given by

$$\frac{V_m}{V_1} = \left[\frac{R^2+X^2}{(R+nr_1)^2+X^2}\right]^{1/2}$$

Putting in the numerical values for the type UVB 230-volt meter these equations become

$$\tan\beta = \frac{nr_1}{8780.2}$$

$$\frac{V_m}{V_1} = \frac{1}{\left[1 + \frac{nr_1}{26223} + \frac{n^2 r_1^2}{75\times10^6}\right]^{1/2}}$$

The errors produced by this change in voltage can be calculated as before. It will be noted that both the phase angle and the magnitude of the voltage applied to the meters are dependent on the product $n \times r_1$. The curve in Fig. 5 therefore gives the error in terms of this product. If, for example, there are 40 meters connected by leads having a resistance of 0.25 ohm, the product $n \times r_1 = 10$ and the resulting error is from the curve —0.22 per cent. It is evident that as stated earlier, the effect of this resistance is less than that produced by resistance in the leads between individual meters. Nevertheless, it is necessary in both cases to keep the resistances of the interconnecting leads to as low a value as possible.

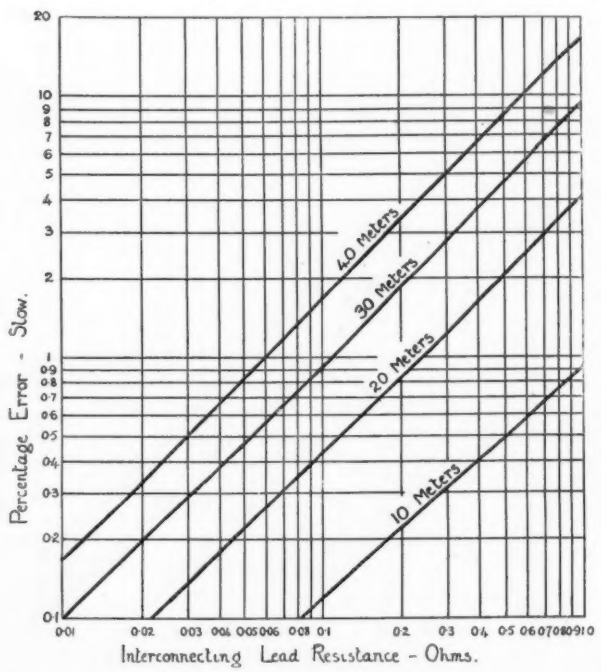


Fig. 4.—Curves giving errors caused by interconnecting lead resistance.

Transformer Errors.

Owing to the fact that any corrections which have to be made for transformer errors are always small, it is possible to devise a simple formula to determine the

overall correction. It is necessary to consider both ratio and phase angle errors of the transformer. Again the problem may be reduced to a single phase one, as even when testing polyphase meters it is possible to consider each element as a separate single phase meter.

In the vector diagram Fig. 6 let

V = true voltage, i.e., primary voltage.
V_1 = secondary voltage, assuming 1/1 ratio
I = true primary current
I_1 = secondary current, assuming 1/1 ratio
α = angle of lead of reversed secondary voltage in front of primary
β = angle of lead of reversed secondary current in front of primary
also let $V_1 = k_1 V$ $I_1 = k_2 I$.

Then the registration of the instrument will be proportional to

$$W_1 = V_1 I_1 (\cos \phi + \alpha - \beta)$$
$$= k_1 k_2 V I \begin{pmatrix} \cos \phi . \cos (\alpha - \beta) - \\ \sin \phi . \sin (\alpha - \beta) \end{pmatrix}$$

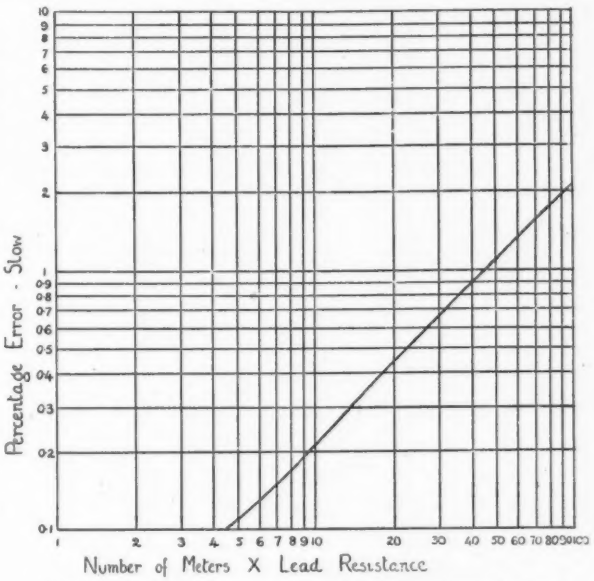


Fig. 5.—Curves giving errors caused by lead resistance between sub-standard and bank of meters under test.

Now $(\alpha - \beta)$ is a very small angle and so we may write

$\cos (\alpha - \beta) = 1$
$\sin (\alpha - \beta) = (\alpha - \beta)$ where α and β are in radians

So $W_1 = k_1 k_2 V I \{\cos \phi - (\alpha - \beta) \sin \phi\}$
$= k_1 k_2 V I \cos \phi \{1 - (\alpha - \beta) \tan \phi\}$

Now $k_1 = 1 + p$ where p is the ratio error of the voltage transformer expressed as a fraction,

and $k_2 = 1 + c$, where c is the ratio error of the current transformer expressed as a fraction.

Then $W_1 = V I \cos \phi (1+p)(1+c) \left\{ \begin{matrix} 1 - (\alpha - \beta) \\ \tan \phi \end{matrix} \right\}$

Again p, c and $(\alpha - \beta) \tan \phi$ are, in general, very small quantities so that products of them can be ignored. Hence

$W_1 = V I \cos \phi (1 + p + c) \{1 - (\alpha - \beta) \tan \phi\}$
$= V I \cos \phi \{1 + p + c - (\alpha - \beta) \tan \phi\}$

or $V I \cos \phi = W_1 (1 - p - c + \alpha \tan \phi - \beta \tan \phi)$

The total correction to be applied to the registration to obtain the true value is

$-p - c + \alpha \tan \phi - \beta \tan \phi$

which can be written as :—

—voltage ratio error—current ratio error + voltage phase error—current phase error. The ratio errors are therefore applied directly, while the corrections for phase angle errors are dependent on the power factor. The nomogram in Fig. 7 enables the correction for each phase angle error to be determined immediately, knowing the phase angle error of the transformer and the power factor of the load.

The signs of the phase angle corrections are as follows :—

Voltage transformer :—

with a leading phase angle error, the correction is positive ;
with a lagging phase angle error, the correction is negative.

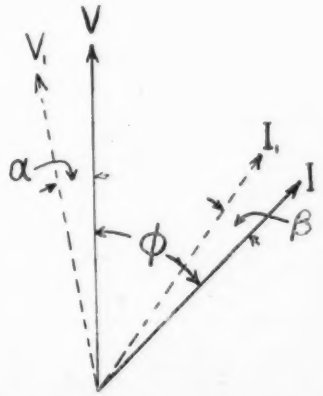


Fig. 6.—Vector diagram for transformer corrections.

Current transformer :—

with a leading phase angle error, the correction is negative ;
with a lagging phase angle error, the correction is positive.

These apply to a load having a lagging power factor. With a leading power factor all the signs are reversed.

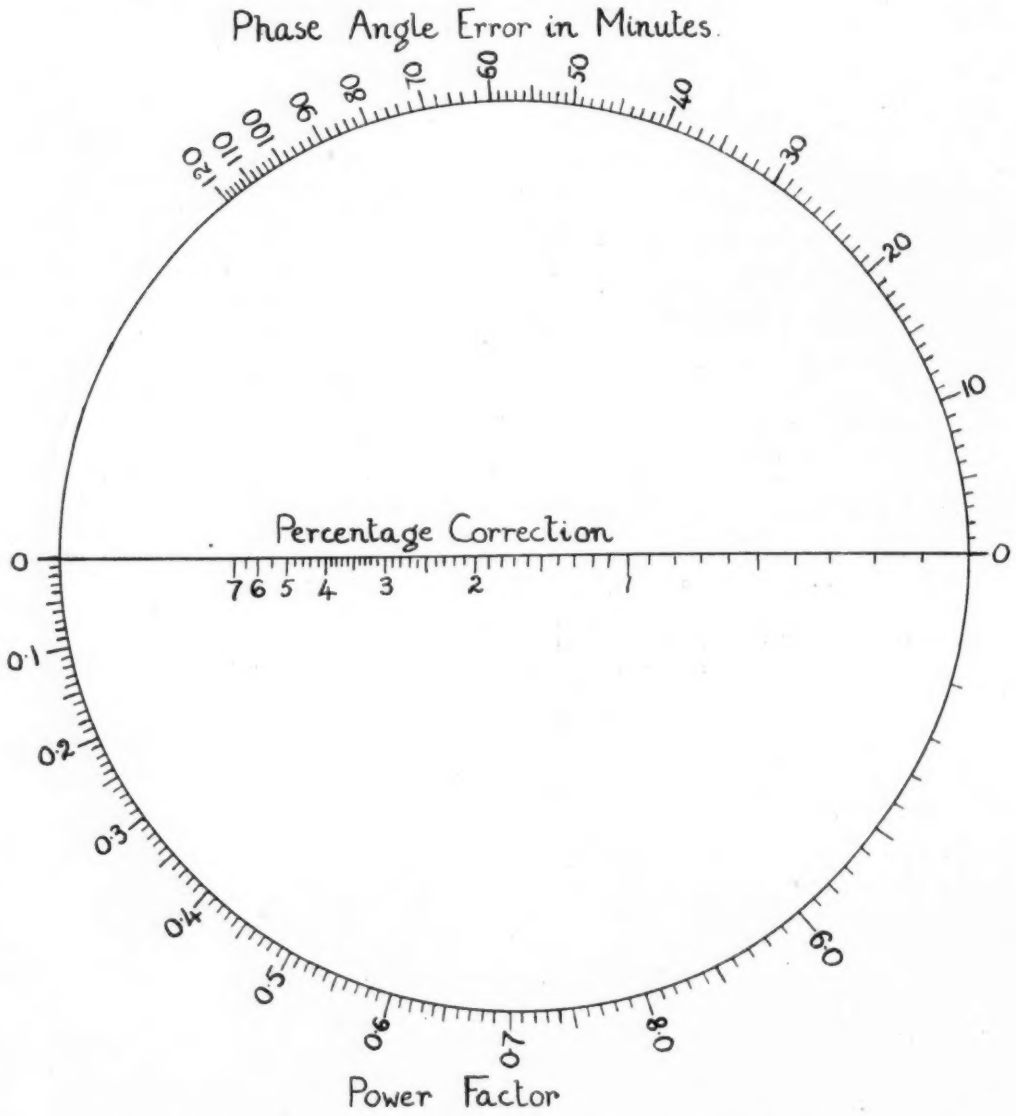


Fig. 7.—Nomogram giving correction to meter reading for given transformer phase angle error.

Two-Pole High-Speed A.C. Motors Class LG and LGS

A range of entirely new two-pole three phase induction motors, having a synchronous speed of 3,000 r.p.m. on a 50 cycles supply, has been developed for such applications as driving high-speed centrifugal pumps and air blowers. These machines have been specially designed for their purpose and are not adapted from any existing 4-, 6- or 8-pole designs, as their speed involves mechanical factors which place them in a separate class.

The motors have been developed primarily as squirrel-cage (class LG) machines, but they can be supplied in slip-ring form (class LGS) when required to meet special operating conditions. Both classes of machines are available either for low voltage or for high voltage up to 3,300 volts. The stator frames are at present standardised in four outer diameters each having two alternative lengths, and the machines can in general be supplied with screen-protected, drip-proof or closed-air-circuit enclosures.

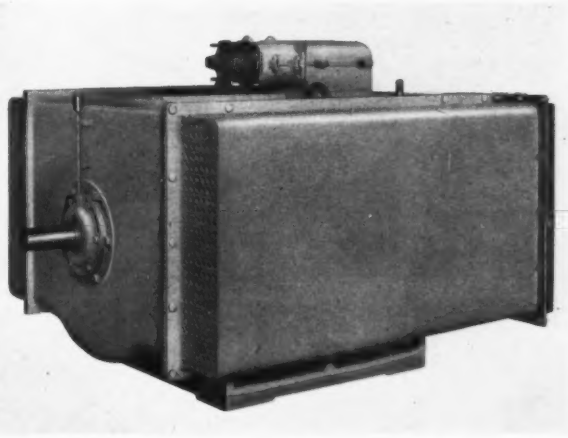


Fig. 2.—Closed-air-circuit two-pole squirrel-cage motor, class LG.

The last-named type of enclosure, as shown in Fig. 2, is perhaps of special interest being particularly suited to situations where impurities in the atmosphere would be injurious to the motor windings and internal parts and would tend to choke the ventilating ducts of a screen-protected machine. The closed-air-circuit motor is pipe ventilated but with the air inlets and outlets connected to a radiator instead of to the atmosphere. The radiator consists of straight tubes through which the cooling air is driven by an external fan on the motor shaft. The hot air from the motor, propelled by an internal fan, circulates round the outside of the tubes in the opposite direction.

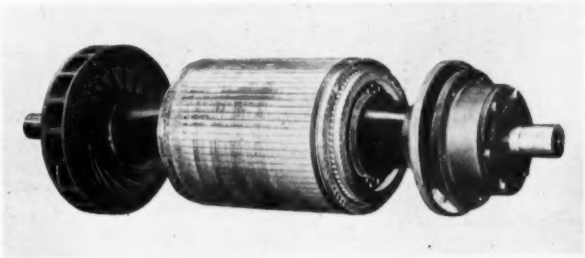


Fig. 1.—Rotor of two-pole squirrel-cage motor, class LG.

The range of H.P.s available in the standard sizes varies with the type of enclosure, the supply voltage, the starting current permissible and the starting torque required. For the lower voltage machines, up to about 550 volts, and with starting currents of 7 to 8 times full load, the outputs are of the order of 160 to 675 H.P. With starting currents limited to about 5 times full load, the range is reduced to approximately 125 to 500 H.P. For 2,200-volt motors the outputs are approximately 130 to 600 H.P., with direct-on-line starting currents of 7 to 8 times full load, or 100 to 450 H.P. with starting currents of 5 times full load. For 3,300-volt motors the outputs obtainable under similar conditions are approximately 200 to 600 H.P. or 175 to 450 H.P. respectively. Both L.V. and H.V. motors can be supplied to comply with starting currents below 5 times full load, but the H.P. from a given frame size is further reduced and special Boucherot rotor construction is required. The foregoing figures apply to screen-protected or drip-proof squirrel-cage machines with a 40° C. temperature rise by thermometer, the starting currents having the usual

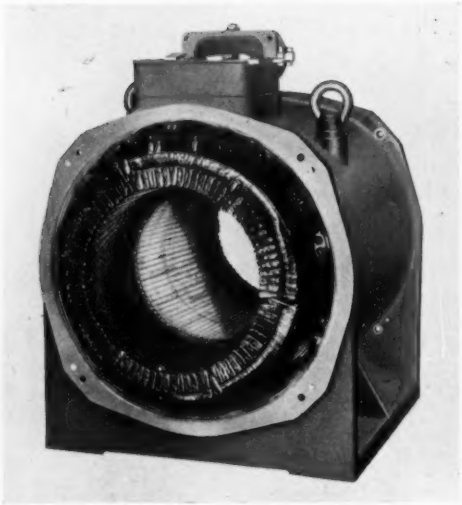


Fig. 3.—Stator of two-pole closed-air-circuit squirrel-cage motor as shown in Fig. 2.

international tolerance of plus or minus 20 per cent.

As will be seen from Fig. 3, the stators of these high-speed machines somewhat resemble those of turbo-alternators, the frames and end shields being specially strong and the end windings substantially braced to withstand the shocks involved in the direct-on-line starting of squirrel-cage motors.

Economically, the correct design for a two-pole machine is to make the core as long as possible, as on any A.C. motor the end windings are non-effective in so far as they make no contribution to the torque. The fewer the poles the longer are the end windings relative to the effective windings in the core and therefore the greater is the proportionate waste. The cores of the LG and LGS machines are accordingly made as long as is consistent with the mechanical strength of the rotors, the shafts of which are very stiff and have

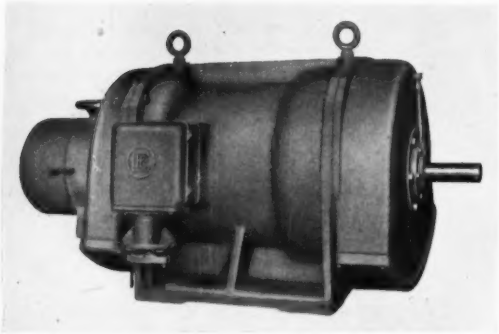


Fig. 4.—Screen-protected two-pole slipring motor, class LGS.

critical speeds well above the normal running speeds. Special care is taken in securing the rotor bars into the end rings on squirrel-cage machines.

The type of stator windings used varies with the horse-power and voltage and can be " hair-pin," " mush " or " barrel " with all clips taped. The larger machines have ventilating holes in the back of the stator stampings. All machines are provided with cartridge-type bearing housings.

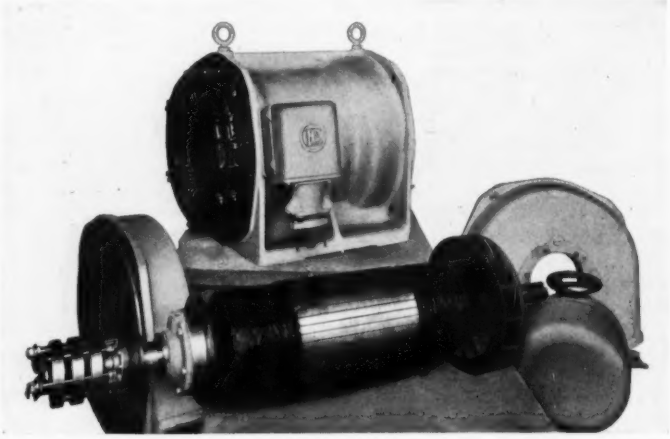


Fig. 5.—Wound stator and rotor and other parts of LGS motor shown in Fig. 4.

Largest Reactors for the Central Electricity Board.

By R. M. CHARLEY, M.C., B.Sc., M.I.E.E., Mem.A.I.E.E.

(The Author is indebted to Sir Johnstone Wright, General Manager of the Central Electricity Board, for information regarding the particular application of these reactors which are installed at Percival Lane, Cheshire.)

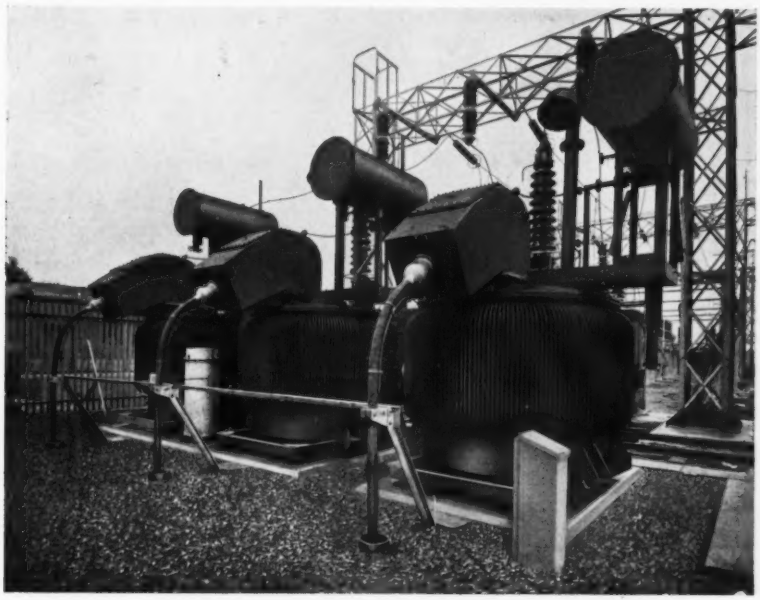
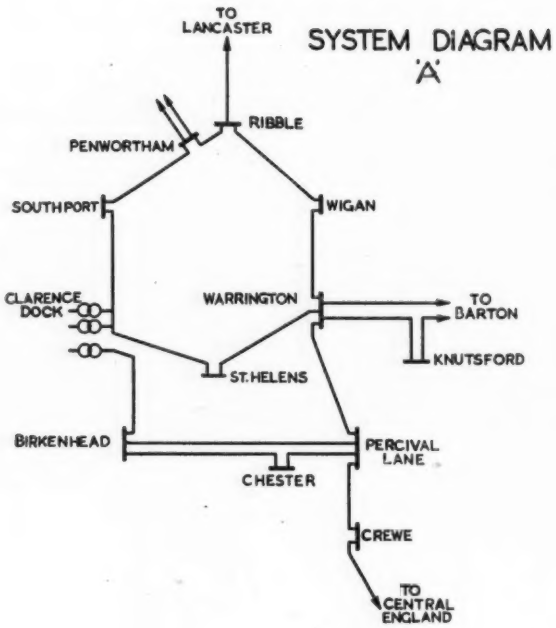


Fig. 1.—Earliest 132 kV. Reactors on the Grid.

In the original conception of the Board's 132 kV. system of transmission the short-circuit rating required of the circuit-breakers, which were of the normal oil-content type, was limited to 1,500 MVA.; but with the ever-increasing capacity of generating plant the level of short-circuit duty rose to higher values and hence it became necessary to introduce reactors and modify switching arrangements in order to ensure that the demands on the circuit-breakers would not exceed the original rating of 1,500 MVA. by more than 10 per cent. One of the earliest installations of such reactors was at Northfleet as illustrated in Fig. 1; this bank of reactors was supplied in 1936 and was designed for a throughput of 50 MVA., and a reactance of 5 per cent. A number of other reactors have been supplied by the Company with values of reactance of 6 per cent. and 10 per cent. Immediately prior to the war extensive modifications to installed switchgear were undertaken by the Board in order to render it capable of meeting the rating as laid down in B.S. No. 116—1937. More recently, further system extensions and increase in generating plant have necessitated still larger reactors and this article describes the installation at Percival Lane where the specification demands a throughput of 90 MVA. and a reactance of 18 per cent. The complete three-phase bank is illustrated in the Frontispiece.

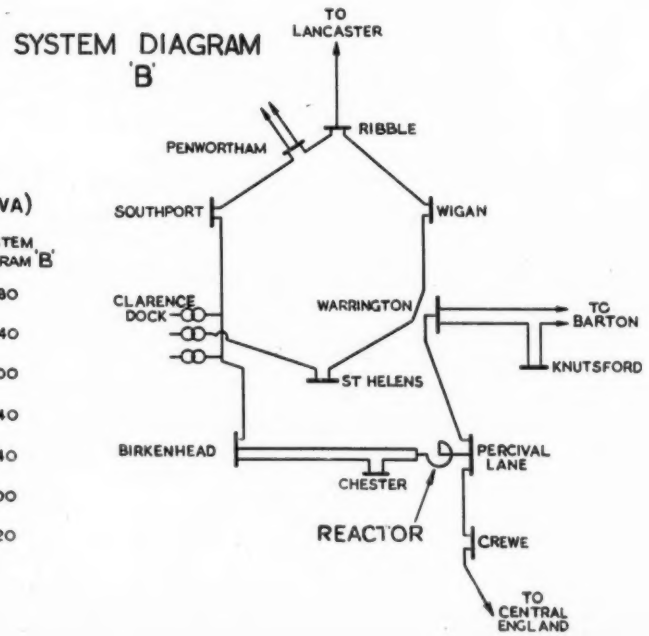
From the purely technical point of view the adoption of a number of small reactors is preferable, but economics must be taken into account, and this factor, together with convenience in operational grouping, determined the policy of installing fewer reactors of a higher value of reactance. The throughput of 90 MVA. was selected as being the probable maximum loading on any associated overhead line, and the value of reactance was fixed at 18 per cent. on



REACTOR AND SYSTEM ARRANGEMENTS IN VICINITY OF PERCIVAL LANE

TABLE OF 132 kV.
SHORT-CIRCUIT DUTIES (MVA)

LOCATION	SYSTEM DIAGRAM 'A'	SYSTEM DIAGRAM 'B'
RIBBLE	1880	1580
WIGAN	1700	1040
WARRINGTON	2380	1500
PERCIVAL LANE	2160	1540
BIRKENHEAD	1440	1640
CHESTER	1360	1100
CREWE	1320	1220



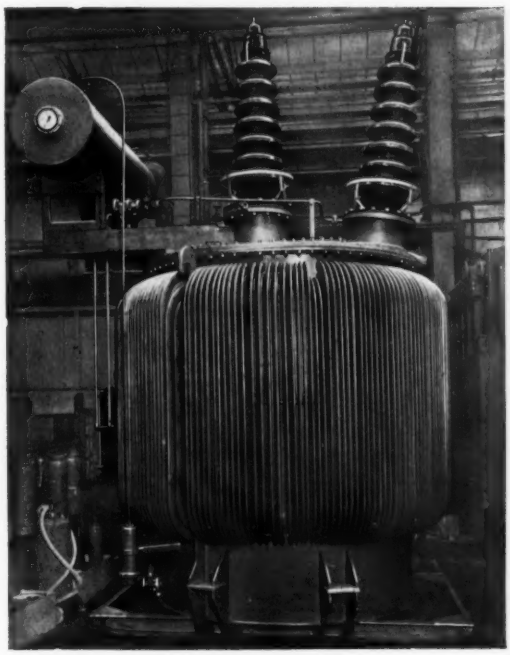


Fig. 2.—Single-phase Reactor unit for Percival Lane.

this throughput capacity on the basis that it was the maximum value that could be tolerated from the point of view of voltage regulation.

In the South Lancashire area there is a big concentration of generating capacity and investigation showed that with the original system connected as shown in Diagram A the short-circuit duties at the respective stations would be as indicated, the maximum value being 2,380 MVA. It was found possible to re-arrange the system connections at Clarence Dock and Warrington, and, with the introduction of a reactor at Percival Lane between the Chester-Birkenhead circuits on the one side and the Warrington-Percival Lane—Crewe circuits on the other, as shown in Diagram B, the short-circuit duties were reduced to the values indicated, the maximum figure being 1,646 MVA. Incidentally, it is of interest that the demands for higher short-circuit duties can now be met by the line of air-blast breakers developed by the Company for short-circuit ratings up to 2,500 MVA. The first example of such an installation is at the Board's switching station at Northfleet.

The reactors installed at Percival Lane are of a type that has been used by the Company for a number of years. The Company's policy is that for all applications, oil-immersed reactors are preferable, but naturally, for 132 kV. service this type is essential. One complete single-phase unit is illustrated in Fig. 2, and the winding is shown in Fig. 3. The conductor is a stranded cable in which each strand is enamelled and the whole is paper covered. The foundation for the coil is a substantial bakelised-paper cylinder; the turns are spaced in the axial direction by sectors of fullerboard and in the radial sense by means of vertical strips of bakelised-paper passing through slots in the radial sectors. Insulation from earth and mechanical support for the winding is provided by a system of washers and blocks of insulation combined with two heavy bakelised-paper cylinders and an outer ring of pillars formed of bakelised paper.

In order to limit stray losses due to the leakage flux to the uttermost the amount of ferrous metal in the proximity of the winding must be reduced to a minimum, hence the winding and insulation is supported on a substantial frame of wood, the members being held together with wooden pegs; a similar frame is mounted at the top of the winding and its members are projected to the sides of the tank where a clamping arrangement is fixed to the tank side in such a manner as to clamp the winding rigidly in position and prevent movement under conditions of short-circuit. One end of the winding is taken to a bushing which projects into the upper end of the

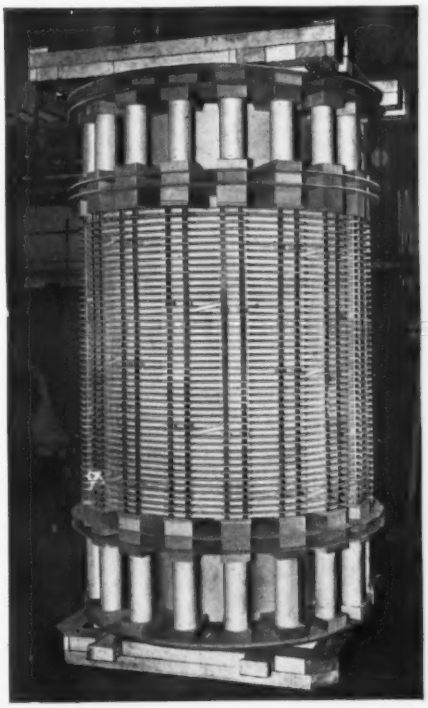


Fig. 3.—Coil for the Reactor illustrated in Fig. 2.

winding and the other end is connected to a bushing located outside the winding. The bushings are of the condenser type with oil-filling ; an arcing horn at the top and arcing ring at the bottom are arranged to give a flashover value of 400 kV.

The reactor winding is contained in an oil tank of circular shape in which radiating surface is provided by elliptical tubes bent in the direction of the long axis and welded into the tank side. This design results in a very robust tank, with cooling provided in the most efficient manner, and it presents a pleasing appearance which feature should not be ignored in designing electrical apparatus. An oil-conservator with Buchholz protective device is provided.

The reactor is of the magnetic shielded type, the shields being formed by sixteen packets of laminations of transformer steel, the laminations being about 1½ inches wide and placed at right-angles to the tank wall and of a length covering the whole length of winding and insulation. This construction gives the minimum loss and the best possible characteristic up to the full value of short-circuit current.

The insulation test applied to the complete reactor is 300 kV. for one minute. The insulation between turns is such that a test pressure of 132 kV. can be maintained between adjacent turns for ten seconds. The loss in a reactor with full-load current flowing in the winding and corrected to a temperature of 75°C. is 60 kW. or 180 kW. for the complete three-phase bank. The total weight of a reactor including oil is 24 tons and the overall dimensions are: floor space 12 ft. by 9 ft. 6 ins. and height 18 ft.

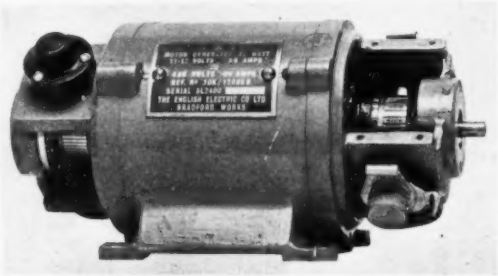
Twenty-Watt Rotary Transformers.

In 1938 The English Electric Company commenced to manufacture rotary transformers on a small scale, and in September, 1939, was approached by the Air Ministry to develop large-scale production on a 20-watt machine. This machine was an original " English Electric " design of the single-armature, two-commutator type, and alternative windings were provided for input voltages of 11 or 18 volts D.C., with an output of 480 volts D.C. at 40 mA.

As the rotary transformers were designed primarily for aircraft use, light weight and compact dimensions were the first two essentials and the majority of the components were die cast in light weight aluminium alloys. The Company manufactured well over 100,000 of this one size of machine during the war years and in addition to this bulk manufacture the Company was entrusted with passing all drawings and design information to three " daughter " firms for them to work in parallel.

The design of the machine necessitated a high-tension winding of 43 SWG (.0036 in.) and the experience gained on fine gauge wires on high-tension D.C. generators for electrostatic precipitation plant over a number of years served in good stead. The high-tension coil consisted of five sections, each of 74 turns, and it was found that if the coil was even a single turn out either ripple was excessive or the range of output volts, which had to be controlled to narrow limits, was exceeded. The majority of small rotary transformers had been of the permanent magnet type, but with the " English Electric " design it was found that better efficiency could be obtained with a wound field which gave a bigger available air gap density and thus reduced the armature loading.

The I.F.F. (Identification Friend or Foe) unit which was operated by these 20-watt machines, is a compact transmitter/receiver device installed in aircraft and whose purpose is to reply to the interrogation of the friendly radio location station by automatically responding to small transmitted signals and returning a stronger coded signal at the same frequency. In addition, an aircraft fitted with I.F.F. equipment can act as a beacon control for other aircraft or can transmit distress signals.



Twenty-watt Rotary Transformer with screening covers removed.

Production at Preston.

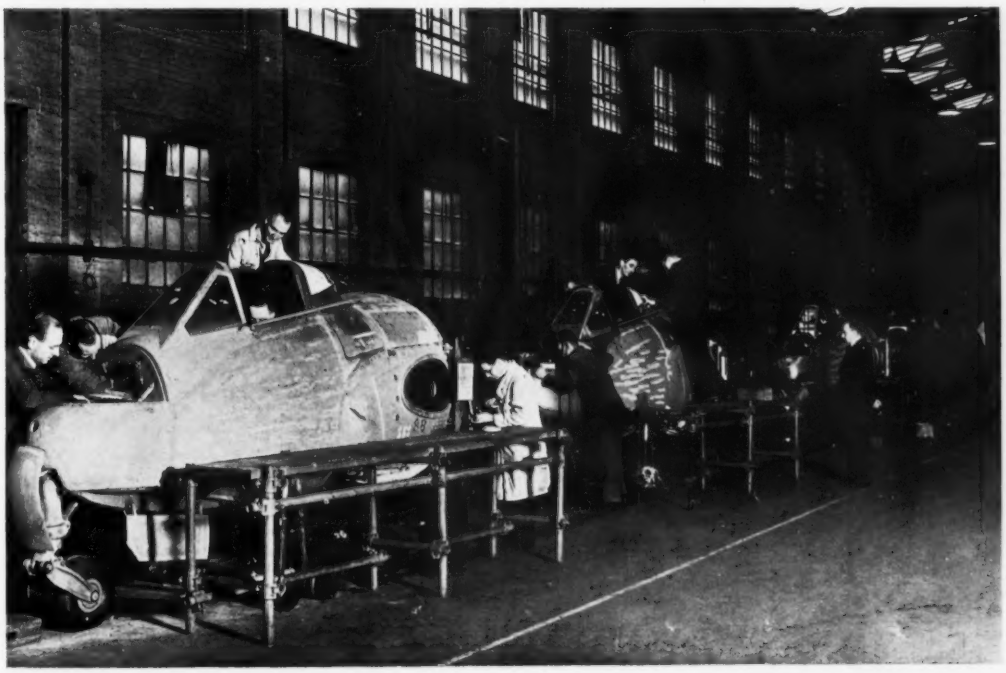
Reprinted from "The Aeroplane," June 14th, 1946.

A well-justified reputation for industrial efficiency has been earned by the associated units of The English Electric Company, which came into being after the last war. Consequently, it was not surprising that in October, 1938, arrangements were made to bring in the Dick Kerr factory at Preston on the production of aircraft for the R.A.F. The first machine to go into production there was the Hampden, output of which was, in this way, increased very largely over the capacity available in the parent company. By the time the line had been changed over to a new type of aircraft more than 770 Hampdens had been built; on top of this another 200 or so had come back to the factory for modification and repair.

The great achievement of the factory in wartime was the production of 2,170 Handley Page Halifaxes, which formed a very considerable proportion of the total output of the quinquepartite Halifax Group. At the time of peak production, somewhere round about 14,000 employees were engaged on this work. Their output of over two aircraft per day, steadily maintained month after month, regardless of the time or year or weather conditions, was a very remarkable achievement.

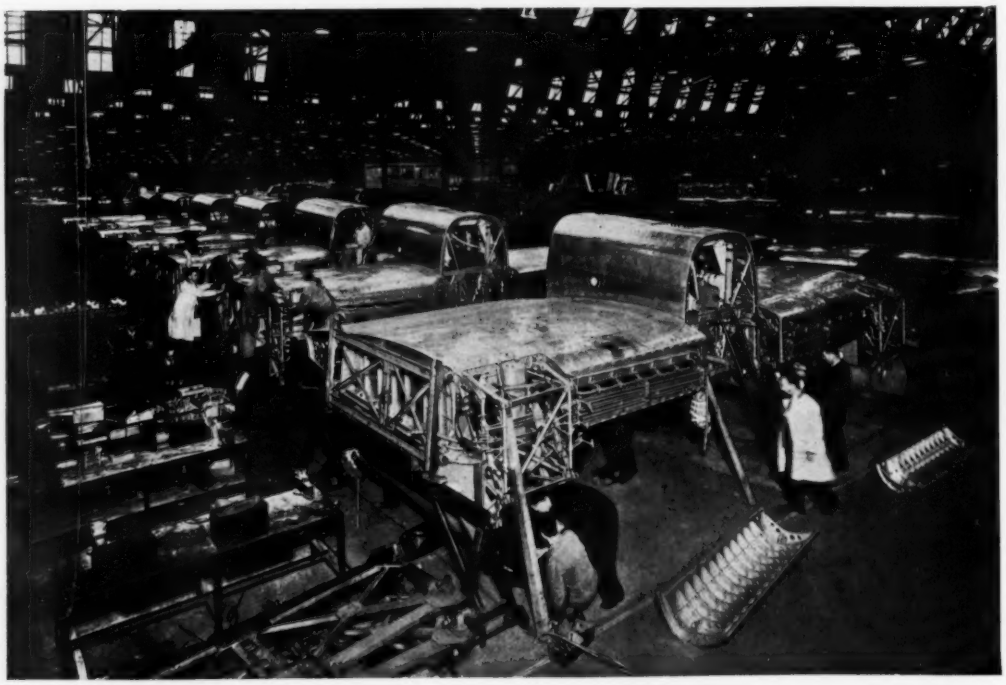
Figures for man-hours per aircraft are often quoted in conversation, but are seldom available for publication. We shall be very surprised, however, if the actual man-hours per aircraft achieved in the building of the Halifaxes at Preston were equalled by any other productive unit, or factory, in the country, if comparison be made on the proper basis.

A very remarkable feature of this war-time effort was the extent of the work undertaken at Preston. Apart from the production of specialist items, such as undercarriage gear, the whole of the production supplies came from within the English



Line of Fuselages: A view of the assembly line of fuselages. The cockpit equipment is fully fitted up and the pressure test recorded before transport to the flight shed for final assembly.

High Bending Moments : The wings are built up in a large jig where the ribs and the skin are riveted on together with the stubs for the tail booms. In this photograph the wing is ready for assembly of the fuselage and tail structure.



Bomber Production : Halifax centre-sections on an assembly line at the Company's Preston works. The photograph was taken during break so there are only special gangs working. During the war-time period 2,170 *Halifaxes were produced.*

Electric organisation, whether it was the moulding of Perspex, for which they developed a special technique, or the protective covering for fuel tanks. In spite of this burden, at one critical period they were able to give very considerable help in the production of heavy complex machined items for the undercarriage gear.

Chairman of the whole English Electric Company is Sir George Nelson, who was knighted in 1943. He was President of the Federation of British Industries from 1943 until 1945.

Mr. H. G. Nelson, son of Sir George, is Managing Director of D. Napier & Son, Ltd., which became associated with The English Electric Company in 1943.

Plastic Art : Moulding of Perspex in all its variety was carried out on a production basis at Preston. This picture shows some of the special equipment and also the wide variety of shapes manufactured.

During the war the production team was headed by Mr. A. Sheffield, O.B.E., the general works manager, and his assistant, Mr. W. Shorrock. Over 3,000 heavy bombers were tested without damage by the chief test pilot, Mr. J. D. Rose, and his assistant.

When the Halifax programme had started to taper off, the firm in April, 1944, began the production of the Vampire. In April, 1945, just a year after the start, the first Preston-built Vampire was assembled and flown.

Now the production is reaching considerable proportions each month, and a number of aircraft have already been turned out. The Vampire has turned out to be far from an easy job to get under way, but now the difficulties have been smoothed out and the line is beginning to move swiftly.

Production Methods.

De Havilland originally built three Vampires in their experimental shop. Later, the third aircraft was sent to English Electric, and after being broken down the parts were used to help the firm get into production. The drawings issued by de Havillands were duly " productionised " to suit the methods of quantity production developed at Preston.

As parent, the de Havilland Company naturally had a resident representative during the development period, who was able to settle many problems on the spot. In general, English Electric have built the aeroplane exactly as specified ; a few slight alterations to the drawing specifications usually took the form of concessions in order to achieve a smoother production of the parts in question.

One of the difficulties experienced in the changeover from Halifax work was that a longer line was necessary, as only one man can work inside the cockpit of the Vampire. As always happens in aircraft production, just as the aircraft was beginning to roll off the line a certain number of modifications had to be incorporated, which involved design work as well as changes in the assembly line.

The two major jobs so far undertaken on the Vampire was the fitting of fixed parts for drop tanks under the wings and the provision of a pressure cabin to the aircraft. The sealing operations were a major consideration, and there were other additions, such as the Westland spill valves to be fitted. Then the cockpits had to be tested up to a ΔP of $3\frac{1}{2}$ lb.

Other changes were the substitution of the Goblin I by the Goblin II turbine early in the line and the fitting of internal tanks, which will be incorporated on the line later in the year. Possibly, next year, they may have to fit the Ghost to the Vampire.

The Vampires are being made in the aircraft section of the works under Mr. R. H. Hollock and the individual components are fully completed before being put on lorries and dispatched to the

Fighter Production : A view of the flight shed showing a number of Vampires in various stages of final assembly. The production is reaching useful proportions.

Flight shed about 8 miles away at Samlesbury where, under Mr. G. Walker, they are assembled on another line and test flown.

The first 25 aircraft were tested by the chief pilot, Mr. J. D. Rose, and the present ones are being flown by Mr. R. Blythe. As there are so many aircraft per month being made he has his hands full (literally). He has reported that so far the aircraft have been generally free from troubles apart from minor difficulties usually associated with quantity production.

The firm have aimed to make as much of the aircraft as possible at Preston, and they also engineer the jigs and factory equipment (even down to fitter's benches) necessary to construct the aircraft. Their war-time achievements here have already been outlined. Naturally, war-time expansions and dispersals, which added to the problems of achieving efficiency, have now been solved by concentration.

The clue to the successful production methods adopted by the firm, in our opinion lies, first, in the efficiency of their tool room, where the high standards are naturally communicated to the rest of the factory, and the other factor is the skilful use of local labour, and particularly in the adoption of incentives to the workers by putting every major section of the factory on piece-work. (Even the typists are on piece-work !)

The way this is done is that from time to time certain good workers are earmarked for rate-fixers and the time set down for the workers to finish each job is the datum by which the entire factory is guided. Thus the inspectors under Mr. Jack Fenton may be faced with, say, a 20 per cent. increase in the production of components by the workers, and if they can hold this extra load they get the increase in pay that goes with it.

The management also arrange it so that if some men are away—sick perhaps—and the remainder can still clear the extra work, they get the extra money but divided into fewer men. This system ensures that if some viewers get over-loaded with work it will pay their colleagues to help them out.

They all then have the incentive to work as a team, and thus in effect it eliminates the danger of putting a job like inspection on piece-work, as skimped work by an individual will achieve negligible results, yet if everybody works hard they will reap the same rewards as the workers. This same system is applied to the semi-skilled and unskilled sections of the factory.

The other point about English Electric is the influence that the tool-room has upon the factory. Mr. W. Harpley has got one of the finest tool-rooms in the country, nearly all the machines—particularly those nearest the camera in the illustration on page 263—are in spotless condition. The department has made some 90,000 tools, of which over 15,000 have been used on the Vampire production, so far. The first five aircraft or so were made largely from components machined from block, but soon afterwards the supply of castings and tools was flowing smoothly. The Standards Room

Production Technique : A battery of electric welders engaged on the production of Halifax parts in the factory at Preston. These machines are designed and manufactured by the The English Electric Company.

is very well fitted out with about two dozen new and elaborate precision measuring instruments capable in some cases of accuracy of 1/100,000 in.

In the main assembly line the Vampire is split up into the wings, the fuselage and the tail unit. The ribs and spars are made and assembled vertically. First the leading edge and skin on one side is assembled to the spar, and in the main jig the wing structure is built up internally. Afterwards the skins are riveted on. In the fuselage stubs for the tail booms are attached and the centre-section with the wing intake-ducts are built up.

Farther down the same shop the booms are made of sheet and riveted into the tubular shape with the fin. They are then stacked up and later all the components receive full protective treatment and doping before being dispatched to the flight shed independently.

In the fuselage shop the wooden frame is made in two parts and the cockpit unit is built separately. Many cockpit assemblies are made together so that one man can fit the internal equipment in each cockpit. The holes are cut for the intake ducts and the cockpit equipment is completely assembled with instruments, controls and moulded Perspex cockpit cover. When the cockpit assembly is complete and ready for the linking up of the controls, it also is sent to the flight shed.

Once all the parts are received at the flight shed, the aeroplanes are rigged remarkably quickly. The Vampire almost is assembled "while you wait." In the short time we were visiting the plant, the tailplane had been fitted and the wings of one machine, the undercarriage and engine were ready to go on. The supply of major components like the Goblin engines and the Lockheed undercarriages have so far been maintained in a steady flow just sufficient to meet the production requirements.

Enough has perhaps been said to indicate that the firm have been able to make a very valuable contribution to the aircraft industry by virtue of their experience of large quantity production. They are a versatile firm (at present producing cooking equipment, rolling stock, including locomotives and, of course, electrical gear).

The Aircraft Design Office, under Mr. W. E. W. Petter, now numbers some 100 draughtsmen. We hope to enlarge on its activities in the near future. There is clearly every chance for the good man to rise to the highest positions—the foremen are nearly all much younger than usual, and indeed this applies to the whole firm. Most of the men in the key positions in the firm have

Sheet Metal Work : A view of the shop in which fuel and oil tanks were produced in the enormous quantities required to meet the war-time requirements of bomber production.

Source of Perfection : A view of the tool room at Preston. Secret of the Company's production efficiency is the very careful productionising followed by the most extensive tooling. This is where the 15,000 tools for Vampire production were made.

worked their way up, and the organisation is such that the young man who is clever can get rapid promotion, with the result that the managers are also relatively young.

This energetic firm with the most advanced ideas—who have not sought publicity during the war—are in a key position, and the experience they have in the quantity production of military aircraft at once puts them in a unique position. It is certain that we shall be hearing about them more and more.

Electric Railway Coaches for New Zealand.

The first two electric railway motor coaches, under a contract received by The English Electric Company from the New Zealand Government, were loaded on board the M.V. "Sussex" at Liverpool Docks on June 14th.

This contract is a repeat of one placed with this Company in 1936 and it is believed that the motor coaches just despatched are the first to be completed in this country and shipped overseas since the war. They are to operate on the Wellington-Johnsonville line of the New Zealand Government Railways, handling heavy suburban passenger traffic at peak periods over severe gradients.

The coaches are of all-steel welded construction and their interiors are sound-insulated. They were built at the Company's Preston Works, incorporating electrical equipment made at the Bradford Works.

Electric Railway motor coach bodies on floating crane for transit to M.V. "Sussex."

The Application of Projection to Inspection.

By S. W. HOLDEN, Chief Inspector, D. Napier & Son, Ltd.

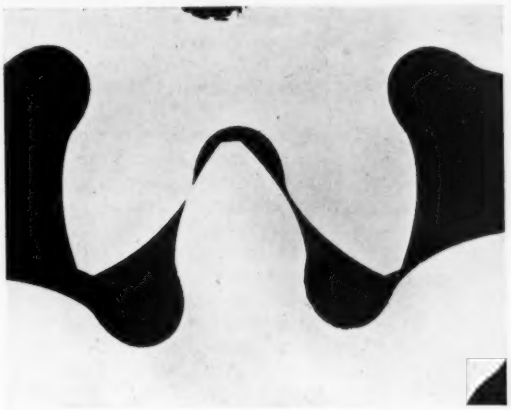


Fig. 1.

With the trend in recent years of aero engine design demanding a greater machining accuracy on profiles, contours, curves, etc., of components, it has been found necessary for Inspection to devise methods for accurate and speedy means of checking.

It will be appreciated that the more normal means available for checking, such as templates, have become inadequate both in regard to the quantity to be dealt with and the degree of accuracy obtained. Further, some of the checks required could not be carried out using the older methods. Inspection Departments have always endeavoured to improve and simplify checking methods, and in this direction very large strides have been made.

Many new types of instruments have been perfected, not the least being the Projector.

It is well understood that the ideal way to check the actual outline of a part produced is to cast its shadow, magnified as required, on to a screen where it may be superimposed on to a large drawing where inaccuracies can readily be detected without the possibility of instrument errors. For years this practice has been used with certain limitations inasmuch as it has only been possible to project the outer contours on such forms where local obstructions do not prevent the passage of the light beam.

It will be obvious that the field of application of this rapid and useful method of checking was, therefore, greatly restricted. Realising the advantages to be gained with the use of projection, efforts were made to overcome this difficulty, and methods have now been evolved, where the profile of parts could be projected by means of suitable devices, even where the shape prevented the passage of the light beam.

An example of simple projection is shown in Fig. 1, which is a reproduction of a pair of oil pump gears in mesh, a direct print of which has been taken on a sheet of bromide pinned to a screen. The actual specimens in this case have a tooth length of 2½ in. but, contrary to general belief, this does not affect the clarity of outline, and gears may be revolved to study tooth action at the very useful magnification of 20 times full size, enabling clearances and contact points to be clearly defined.

In Fig. 2 is shown the blade form of an impeller

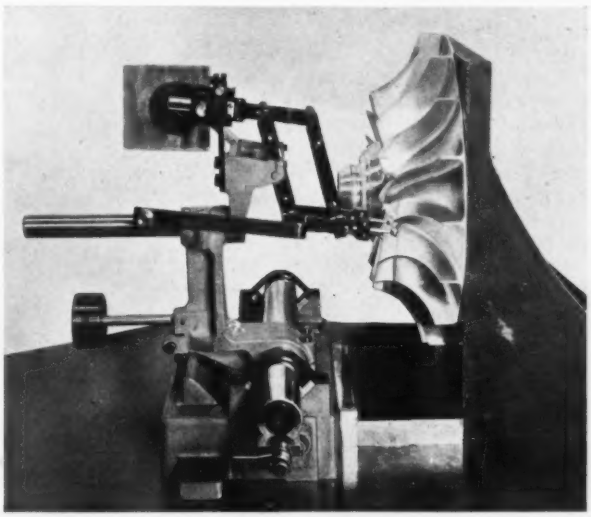


Fig. 2.

Fig. 3.

being traced by means of a precision pantograph. This instrument has a tracing stylus linked to a scribing point which traces on smoked glass the exact contour of the specimen, plus the radius of stylus. A series of arcs struck from the projected contours thus produced will then result in an accurate outline of the actual form simply amplified. This method is not dependant upon a free passage of the light beam.

Fig. 3 shows the form at three sections of one of these blades all superimposed on, and relative to, a common datum enabling position, as well as shape and thickness, to be determined. An accurate check can thus be made more simply and with a considerable saving of time over normal methods.

In the manufacture of engine sleeve valves, it is necessary to eliminate local irregularities in both bore and outside diameter to keep oil consumption down to a reasonable level. At one time it was found in practice that occasionally a varying number of minute corrugations were present on either or both of these diameters, and although these were visible after running, it was extremely difficult to measure these irregularities during manufacture, and so trace this trouble to its source.

In such cases, whilst magnifying surface finishes very greatly, it was not possible to project the whole form of the part when magnified to the same extent. Apparatus was, therefore, devised which would magnify the surface finish without enlarging the whole form in the same ratio. This, and many other applications, were achieved by making use of a line scratched on a smoked glass slide which could then be magnified on a projector to the required amount. Further scope is afforded by this method inasmuch as, not only can the actual form be scribed on the slide, but, where necessary, a diagram representing its departure from drawing requirements can also be obtained.

Some measure of the difficulties can be gauged from the fact that owing to the thin section and relatively large diameters, the difference between the measured diameter of the sleeve bore with the part placed in the vertical and horizontal positions was .003 in. due to deflection by its own weight, and that finger and thumb pressure

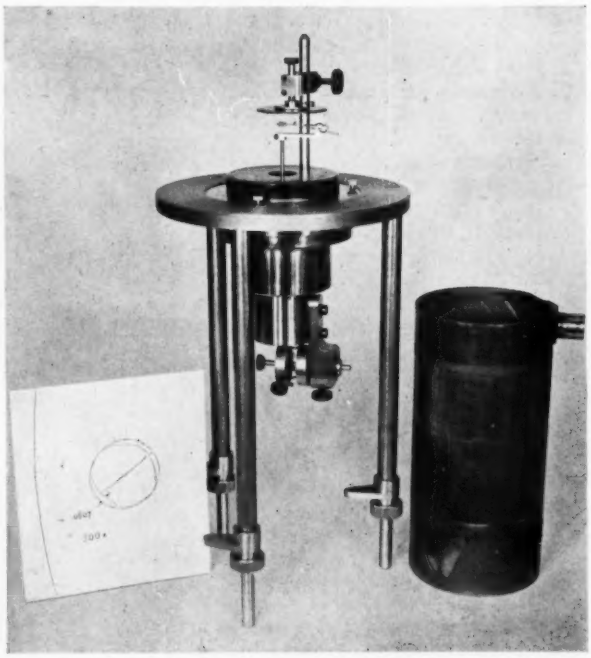


Fig. 4.

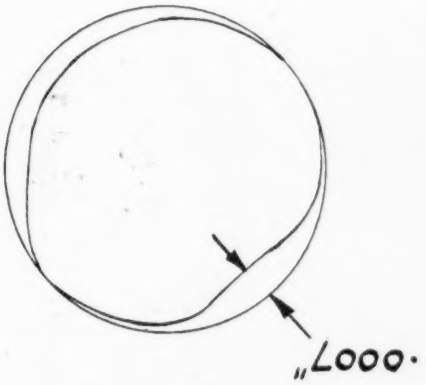


Fig. 5.

across the diameters caused a deflection of .010 in.

With these points in view, a Recorder was devised with a support for the sleeve at top and bottom which traced around the bore on a sheet of smoked glass, amplifying by 20 times the departures from true roundness and reducing the actual bore diameter 25 times. The resultant record when magnified 50 times by projection was double the mean bore diameter with all the irregularities amplified 1,000 times.

The instrument was also provided with a small device for superimposing on the image produced a true circle for comparison. The Recorder, and a specimen slide, are illustrated in Figs 4 and 5.

To further the research into the measurement of irregularities of sleeve valves, the Recorder shown in Fig. 6 was made to plot undulations or winds in a plane parallel to the axis, although it has been subjected to many other uses since. This instrument will plot the waves, apart from the texture of the finish, in a surface 11 ins. long, and is capable of varying magnification

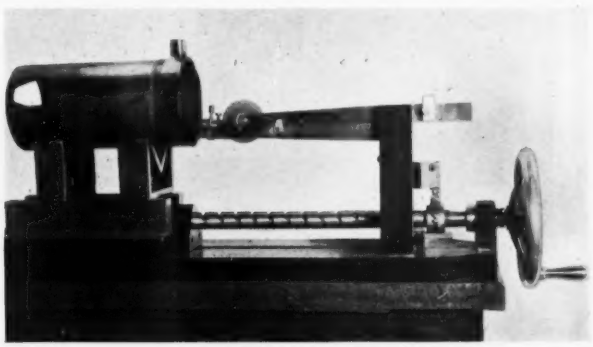


Fig. 6.

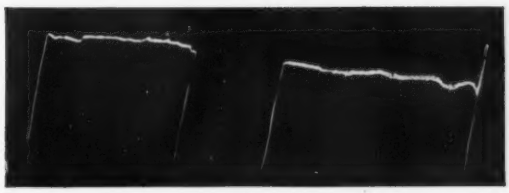


Fig. 7.

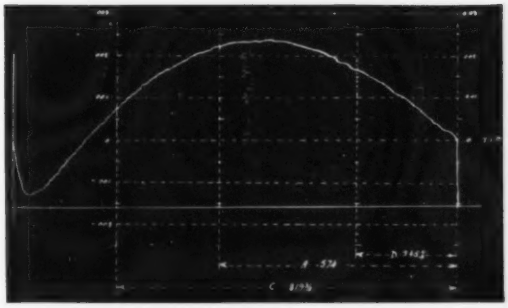


Fig. 8.

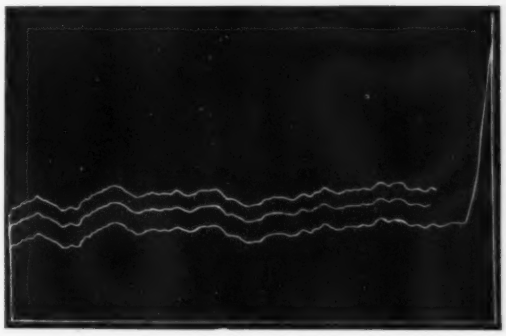


Fig. 9.

both horizontally and vertically ; thus, by selecting a suitable projection magnification, almost any ratio of these two elements can be obtained.

Fig. 7 is a copy of a cylinder block bore tracing recorded on this instrument showing texture superimposed on surface waves. The break in the record indicates the position of the inlet port relative to the end faces.

One further sample of the assistance afforded by projection in defining very small amounts, is shown in the graph—Fig. 8—taken on a Napier Gear Recorder which shows the departure from true involute of a gear tooth of " corrected " form. This indicates, by means of the

screen superimposed, the exact height of the curve in increments of .0001 in. at the prescribed positions, and at the same time is sufficiently sensitive to plot the surface finish normal to the pressure line which, in this case, is quite good. On the other hand, the example shown in Fig. 9 taken of a true involute helical gear, is obviously rejected on this account. The three graphs in this instance represent the tooth profile at the ends and centre as a check on the helix angle.

Fig. 10 is an illustration of this Recorder with one of the gears in position for checking.

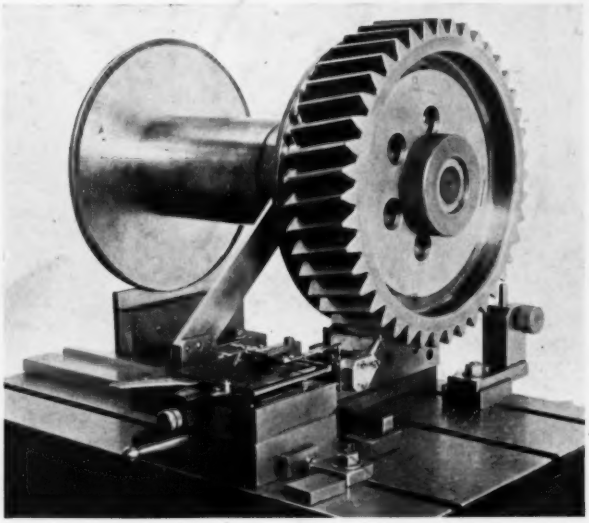


Fig. 10.

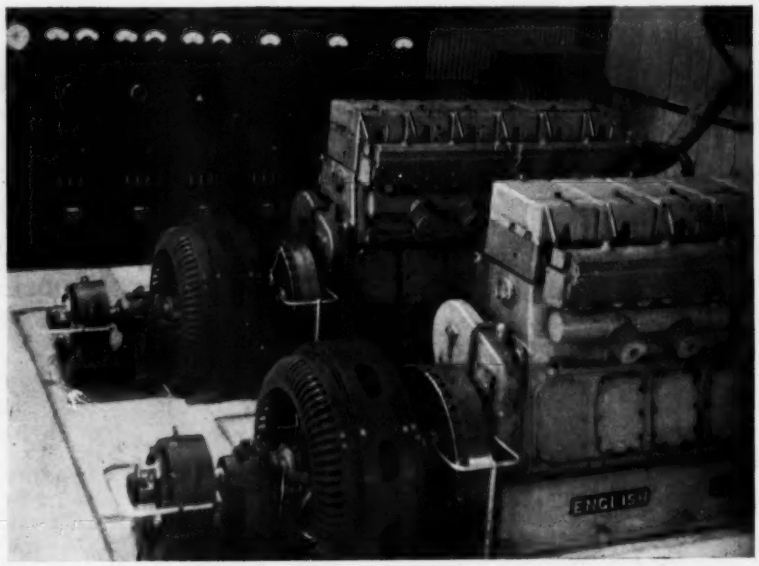
"English Electric" Diesels Run by the Enemy

A tribute to the reliability of "English Electric" Diesel Engines is contained in a letter from Mr. A. T. Allen, of Alderney, Channel Islands. Writing on February 19th, 1946, to The English Electric Company, Mr. Allen says :—

"In 1938 you installed for the Channel Islands Granite Company, Alderney, to the order of Messrs. S. H. Heywood, Manchester, two 6K 330 H.P., 600 r.p.m. Diesels, and I assisted in their erection and afterwards ran them until the evacuation in 1940.

During the occupation they have been run by the Germans with very little attention and no spares. It might interest you to know that one of the engines, No. IH762, ran for two years without stop, so that speaks well for the engines."

The two engines, and their associated generators, are shown in the illustration.



Two 330 H.P. K-type Diesel generating sets in the Channel Islands Granite Company's Power Station.